THE DESIGN AND TESTING OF AN AUTOMATIC RF CONDITIONING SYSTEM FOR THE COMPACT MEDICAL CYCLOTRON

Lei Yu, Yin Zhiguo, Li Pengzhan, Ji Bin, Zhang Tianjue, Wang Chuan, Wei Junyi,
China Institute of Atomic Energy, P.O.Box 275(3), Beijing 102413, China

Abstract

The multipacting phenomenon for the compact medical cyclotrons is special, due to the present of the fringing magnet filed inside the accelerating structure. And it will become more interesting, when the vacuum system is equipped with diffusion pump. A method used for CYCIAE-14 cyclotron cavity conditioning was reported in this paper, together with the testing results of an automatic conditioning circuits designed on such basis. Apart from traditional Low Level RF control, in which close-loop regulation is played as an important role, the automatic conditioning system emphasis on the cavity startup process. It takes advantage of the modern digital signal processing technique, combined with the direct digital synthesizer to accurately limit the reflection, will condition the cavity by means of the sweeping frequency, using the low RF driven power, in continuous wave mode. After successful establishment of the accelerating voltage, the system would maintain turning of the resonator and would decrease driven power once in a while, until the driven power is below a preset limit or the Dee voltage collapse again. In the latter case, the system will repeat the whole process until reaches the first one or interrupt by the operator. The electronics are designed and tested first; it will be used later in the commissioning of the RF system of other compact medical cyclotrons built by BRIF division of CIAE.

INTRODUCTION

The RF system is an important part of CYCIAE.-14 cyclotron [1]. It is very important to condition the RF cavities effectively. Since it determined that whether the cyclotrons can turn into the normal operational stage as quickly as possible.

When the cyclotrons are in operation, usually, the periodical servicing and maintenances will break the vacuum. To achieve the required resonator voltage as soon as possible, we should condition the RF cavities again after regaining the vacuum degree .

At present, a lot of kind of accelerator which including the linear accelerators, the energy storage rings and the synchrocyclotrons were all faced with the problem that the RF cavities need to be effectively conditioned to restrain the multipactor in them. The science researchers of them had made a lot of study on it. They had attempted to use various conditioning methods and make them automation [2] [3] [4]. Thus it can be seen that it is significant to study and implement a safe and efficient automatic conditioning system for the operation of the RF system of the cyclotrons.

THE METHODS OF THE AUTOMATIC CONDITIONING SYSTEM

The multipactor were discovered by Gutons in 1924 [5] [6] [7], and in 1934 Philo T.Farnsworth presented the multipactor and confirmed it with experiments. At present, the multipactor in the valley magnetic field of the cyclotron can be simulated through the large-scale programs which is the parallel numerical calculation. Through observing and studying, we find that the multipactor of the CYCIAE-14 usually appears at the power from 1 kilowatt to 1.5 kilowatt.

Therefore, we have presented a new method of the RF cavities conditioning, it concluded four steps as follows: a). At first, the system use the low duty ratio pulse wave as the input signal. When the multipactor appears, demarcating the driven power and the voltage of the cavities, as the Fig.1. b). Secondly, without the magnetic field, the input signal changes to the CW power.The CW power sweeps the RF cavities frequency and condition the cavities, in order to bake the surface of the cavities for gassing. c).Thirdly, with the magnet field, using the CW power sweeps the resonance frequency point of RF cavities. After the power going through all regions of the multipactor, add the amplitude modulation. The amplitude of CW decreased with the time, to condition the cavities. d). Finally, with the magnet field, we use new method to keep the tuning frequency. To ensure that the high power and low duty ratio wave condition the cavities is achieved.

The conditioning method above is summarised from the conditioning process of the CYCIAE-10, the CYCIAE-14 and the metallic experimental cavities of the CYCIAE100. The automatic conditioning system of this article would achieve the step b), step c) and step d) to avoid the complexity of the aritificial operation.
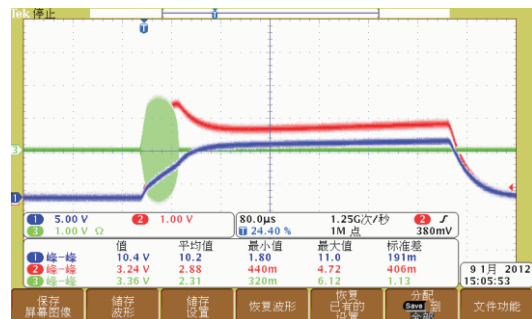

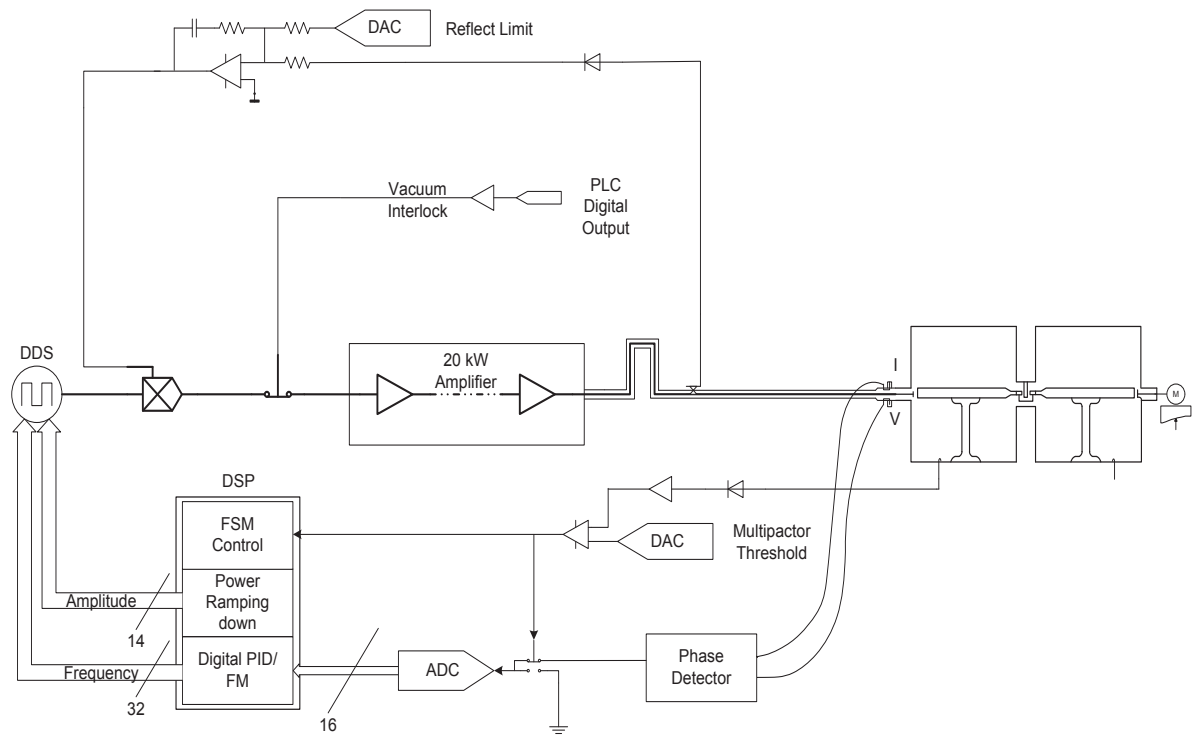Figure 1: Demarcating the multipacting power.

Figure 2: The CW conditioning mode.

THE DESIGN OF THE AUTOMATIC CONDITIONING SYSTEM

According to the experience of the artificial condition before, if we want to condition the cavities effectively, weshould demarcate every voltage when multipacting appears. Then the system enter into the CW conditioning stage. After going through all of the voltages of multipacting area, we used CW power to condition. The amplitude for CW power decreased gradatim.

Achieving the function of CW conditioning is a very important step for the automatic system. The block diagram of the CW conditioning mode is just as Fig.2.

In the initial stage of the CW condition, the Moore machine of the DSP judge that the feedback of the cavities' voltage is smaller than the highest voltage of the multipacting area. Then the system launches the FM mode. We set the centre frequency at the frequency of the cooling cavities, The sweeping range is as the 3-5 times of the cavities' half bandwidth. The amplitude of output signal for the DDS is set at the maximum of the VSWR value which the RF power source can tolerate. Taking the CYCIAE-14 for example, the output of the DDS is -16dBm, and the downward ramping is shutted. The system set the DAC's limit value of the adjusted loop circuits of the reflected power to a half of the biggest reflected power value of the RF power source. And the value of the power source CE-20000 from ASI corp. is 1kW. These steps can protect the reflected power from exceeding the limit during the sweeping condition.

Another significance of sweeping is that it can protect the sensitive parts as coupling windows from exposing under the impacting of the multipactor. After the system overcoming the multipacting area, the voltage comparator of the cavities would trigger the turning of the DSP's state to make the system access the conditioning mode. In this mode, the system would start the PID controller of the DSP. The output of the detector would be used to tune the frequency of the DDS. And it would achieve the function of tuning loop. When the state of the DSP had changed, the software would initiate the timer for the DDS to reduce the "Amplitude Scale Factor" which is equal with 0.1dB every other 5-minutes. The step can accomplish the amplitude-reducing condition until the multipactor appear in the cavities again. Thus, a conditioning repeat would be done, and the system would restart. What the different with the first condition is that the driven power of the DDS would take the middle value of the repeat conditioning voltage area last time. Conditioning some times like this, the system could access the step of the pulse condition.

The key point of the pulse automatic condition is the tuning of the RF cavities. Under the state of the pulse, the system tune with detecting detuning angle during the pulse and using the sample-hold mechanism. However, the sustained time of the RF signal is short at the low dutyfactor, the characteristic time which the voltage could build in the cavities for must be deduct, and the system also need to judge whether the voltage of the cavities could be built successfully and the cavities are sparking or not, so the expected effect is not ideal. When the system

was designed, we had made some innovation based on the method above. We had used red curve where there was no RF signal at first and which is shown in the Fig.3, i.e. had used very low power RF signal to drive the cavities, and used the time to detect the detuning angle of the cavities. At the same time, the system would stabilize the output of the detector with the sample-hold circuits to tune. The principle is that the accelerated gap of the cavities can ensure that the power area where there is no multipactor at the low power area must be found.
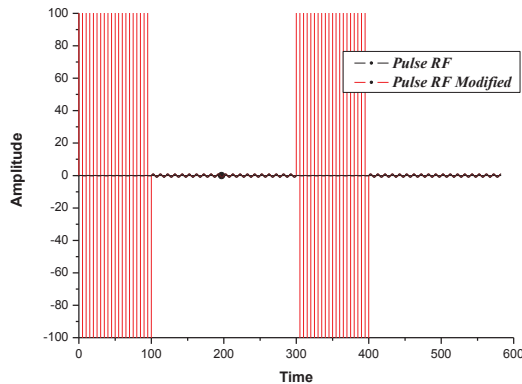

Figure 3: Advanced pulse tuning.

In the pulse conditioning mode, there are not intrinsic differences between this system and the traditional LLRF on the designing. So we won't describe the designing details.

There are some advantages and disadvantages of this pulse conditioning method:

• Tracking the frequency more accuracy because of using the longer unoccupied time when low dutyfactor pulse driven the cavities.

• During the pulse width, when the cavities spark and multipactor happening in high power, the system will make the tuning of the cavities not be influenced.

• Because the cavities driven with the lower average power, the detuning angle changes slower and the average power is also limited.

• The difficulty is the dynamic range of the detector must be big enough.

THE REALIZING AND DEBUGGING OF THE CIRCUITS OF THE AUTOMATIC CONDITIONING SYSTEM

The core of the automatic conditioning system is the CW conditioning module. The module used the designing frame of the LLRF that designed by BRIF of CIAE for reference. And it had been designed as a VME, 3U module to layout, solder and debug. At present, the CW conditioning module has been jointed debugged with the other modules.

Considered the modularization of the designing at the beginning of the system design, the hardware resource could be multiplexed. The other modules of the system as the digital control module and the tuning loop module could be soldered, tested with the existing LLRF system.

For testing the CW conditioning module alone, we had set up a desktop testing environment. And the closed loop test indicates that the module can limit the reflected power effectively. And then, we had expanded the unit testing environment to build a testing environment of the CW conditioning systemic function. In this environment, we could imitate that the feedback voltage of the cavities whether exceed the voltage of the last multipacting area or not. And the changing of the wire length can replace the phase-frequency response. The result of the experiment had indicated that the system could sweep frequency with the given power when the feedback voltage was small then the set point. And if we change the volume of the reflected power, we could observe that corresponding regulation of the PID controller. We could observe that the tuning loop was operating when the feedback voltage exceeded the set point, and the frequency would converge at the frequency which had been defined by the length of the coaxial cable. Then the changing of the length of the coaxial cable can change the frequency of the system. And the amplitude-down process which is controlled by the DSP, could be observed.

CONCLUSION

At the interval of the debugging of the CYCIAE-14, the early of June, 2012, in the case of non-magnet-filed, the joint debugging with the CW conditioning for the RF system had been achieved. The regret is that we had missed the best using time, because the design and experiment for the RF controlling were the first time for us. But the design for the system, especially the function of CW conditioning, must play the proper effect in the future.

REFERENCES

[1] Tianjue Zhang et al., "Overall Design of CYCIAE-14, a 14MeV PET Cyclotron", Nuclear Instruments and Methods in Physics Research B, Volume 269, Issue 24, p. 2950-2954.

[2] S. Deghaye et al., "Overall. Automatic Conditioning of the CTF3 RF System", EPAC 2006, Edinburgh, UK, TUPCH144.

[3] H. Sakaki et al., "Automatic RF Conditioning System for SPring-8 Linac", 678-12, Japan.

[4] S.M. Shajedul Hasan et al., "EPICS Based High Power RF Conditioning Control System for the SNS Accelerator RF Test Facility"., ICALEPCS 2005, PO2.003-2.

[5] C. Gutton, Compt. Rend. 178, 467 (1924); C. Gutton and G. Gutton, Compt. Rend. 186, 303 (1928); H. Gutton, Ann. Phys. 13, 62 (1930).

[6] P. T. Farnsworth. "Television by electron image scanning". J. Franklin Inst., 218:411-444, (1934).

[7] P. T. Farnsworth. "Multipactor phase control", Technical Report 2071517, United States Patent Office, (1938).